FIELDIANA: BOTANY

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Geography and topography

The Tehuacán Valley of Puebla, Mexico, lies in the southeastern corner of this state and extends into the northern edge of Oaxaca. It is roughly 170 km. long and 40 km. wide. Lying just inside the Sierra Madre Oriental, or Sierra Zongolica, which divides Puebla from Vera Cruz, the area falls in a series of giant steps from the northern end to the southern terminus in northern Oaxaca. The western limit of the valley is marked by the lower masses of the Sierra de Zapotitlán. Its northern end serves as the route for the Mexico City–Vera Cruz highway which approaches, but does not pass through the city of Tehuacán, the administrative center for the area.

The topography in the valley is varied. Over much of the area, gently rolling hills form the outliers of the mountain masses to the east and to the west. Occasionally hills rise abruptly to heights of several hundred feet. Immediately to the west of Tehuacán, the limestone cliffs rise sharply to the level summit locally called La Mesa. Eastward from the city, Cerro Colorado can be distinctly seen with its high, reddish-colored cliffs. Over much of its expanse, the Tehuacán Valley is characterized by wide plains which slope gently to the south. The extreme northern end of the area lies at elevations of 1500 to 1700 m. across the valley bottom. Because of the drainage patterns and the geological formations, the elevation drops in a series of steps to the confluence of the Río Salado and the Río Grande where the elevation is less than 700 m. At intervals, a major drop in elevation is marked by a rough scarp which crosses the valley in a northeasterly-southwesterly trend. The northern portion is drained by the Río Salado, the southern by the Río Grande. These rivers merge to become the Río Santo Domingo which cuts abruptly eastward through the ridges of the Sierra Madre. Numerous tributaries bite into the flanks of the mountain ridges on either side of the valley. Occasionally they cut deep into the mountains to form extensive valleys; Barranca de los Mangos and Barranca San Antonio furnish major routes of access into the valley for the mountain inhabitants. Generally, the stream beds are dry.

Even the Río Salado has only a minor flow of water in the wet season but its bed is as much as a half-kilometer wide at some points.

To the south near the city of Teotitlán del Camino there is a series of high hills with nearly vertical lime rock sides, which dissect the valley into small level areas. Beyond this city the broad valley of the river becomes the principal feature of the landscape with rolling hills rising into the mountains on either side.

FIG. 10. Farms in the moist valley near Orizaba to the east of the Sierra de Zongolica. Note the nearly complete vegetational cover including the continuous cover of trees on the mountains.

NATURAL VEGETATION

The natural vegetation of the Tehuacán valley can be roughly classed as thorn-scrub throughout below an elevation of about 1800 m. Above about 1800 m. elevation on the ridges to the east to the upper reaches of the Sierra Madre, the natural cover of the land is oak-pine forest. Only the summit of the westernmost ridge is covered with montane rainforest above an elevation of about 2800 m. The rainforest vegetation is the least disturbed of the three vegetation types. Much of the area formerly covered by oak-pine forest has been cleared so that wide stretches of the mountainside have no tree cover. While many of the fields have been abandoned, grazing

FIG. 11. Mountainside farms on the western side of the Sierra de Zongolica above Coxcatlán. The vegetational cover is much less complete here below the edge of the oak-pine forest area. The fields are largely in the area of the former oak-pine forest.

on the grass and brush cover discourages reproduction of tree species on such areas. Much of the mountainside facing the valley will never recover fully as the pressure to use this land, within easy reach of the markets in the valley, is great.

The upper reaches of the Sierra de Zapotitlán to the west of the valley show the eventual fate of these montane agricultural areas. The mountain tops were once covered with oak-pine forest. Today only occasional oak trees remain among the broad stretches of thorn-scrub and cacti. Frequently, the soil layer is very thin, exposing outcrops of rock every few feet along the surface. In some of the better favored hollows, fields are still cultivated, but most of the land has been converted to pasture of a very poor sort on which are grazed a few cattle and many sheep and goats.

The larger part of the valley area below the 1800 m. elevation is covered with thorn-scrub and cactus vegetation of a single kind in

which the species composition varies but little. Local differences in soil and moisture lead to the predominance of a few of the species over the rest. Local forests made up nearly exclusively of one or another of the species of columnar cacti are common. These are usually on hill slopes. In other places, broad-crowned trees, frequently with smooth, peeling bark, predominate.

Two variations in the natural vegetational cover are due to major differences in the local geology. The more widespread of these variations is a xeric facies of the valley vegetation on the numerous patches of limestone. Where the limestone outcrops or lies just beneath the surface there are very few trees. The two most prominent trees found in such areas are the spiny, orange-flowered *Fouquieria formosa* HBK., with sparse foliage and peeling greenish-tan bark, and the strange liliaceous tree, *Beaucarnea gracilis* Lem., with trunk bulging widely at the base and the branch ends carrying brushes of long narrow leaves from which rise the plumes of inflorescences. The remainder of the cover in these areas is shrubby vegetation accented by the large bulk of the barrel cactus, *Echinocactus grandis* Rose, or the broad mounds of *Ferrocatcus robustus* (L. & O.) B. & R. At times the naked, gray-green clumps of "candelilla," *Euphorbia antisyphilitica* Zucc., form nearly pure stands.

The second of the specialized vegetational areas are the soil patches in which a geological formation bearing saline springs has produced marked saline plains. Irrigation over a very long period of time with the highly mineralized waters from the large natural springs, which rise in the northern end of Tehuacán valley, has also resulted in saline areas. The first kind of saline area is clearly seen around Petlanco, a hill which, from the clean conical shape and the rough igneous rock outcropping near its summit, appears to be a much degraded volcanic core. The second kind of saline soil condition is found near the Cerro San Andrés just outside of San Gabriel Chilac where heavily mineralized waters from the upper reaches of the valley have apparently been used to flood the fields for centuries. A part of this area is so saline that little vegetation grows on it. Most of the species of trees and shrubs of these areas are the same as those of the general vegetation across the valley. A few species of salt-loving plants, such as *Juncus* aff. *robustus* Wats., forming dark stiff clumps, and *Trianthema portulacastrum* L., which forms low, gray-green clumps of foliage, emphasize the soil's salinity.

This, then, is the basic background, and a rather unlikely one, against which the story of the agriculture of the valley is laid. The

information this presentation is based on was gathered during field exploration in the summer of 1961. I was invited to join the Proyecto Arqueológico-Botánico of the R. S. Peabody Foundation to identify the wild plant remains recovered during the excavation of several caves in the valley. Funds for the Proyecto were from grants made by the National Science Foundation and the Rockefeller Foundation to the Peabody Foundation. The work is under the direction of R. S. MacNeish of the Human History Branch of the National Museum of Canada. The cultivated plant remains from the excavations will be studied and described by a number of specialists at some future time. As a background for this work and as a natural outgrowth of my survey of the contemporary vegetation and land use in the Tehuacán valley, the current description of the agriculture is presented.

AGRICULTURE

Agriculture in the area of Tehuacán may be conveniently divided into that practiced through the length and width of the valley below the edge of the oak-pine forest at about 1800 m. elevation and that practiced on the mountain slopes above this elevation. The differences in practices in these areas are based largely on the available rainfall during the growing seasons, or on the distribution of rainfall during the year. Weather in the valley is largely determined by the regimen imposed on this area by the trade winds of the Gulf of Mexico to the east. Much of Mexico measures its seasons by a precipitation pattern divided into a dry season, extending approximately from October to March or April, and a wet season, which extends over the remainder of the year. Variations in the pattern are often a result of local topography. The weather in the Tehuacán valley is largely controlled by the mass of the Sierra de Zongolica to the east. These mountains rise to elevations in excess of 3000 m. as a succession of northwest-southeast-trending ridges. Moisture-laden clouds blowing into the land from the Gulf of Mexico are forced against the mountains and drop much of their moisture load on the eastern slopes or on the mountain tops. Only unusual build-ups of clouds during storm periods result in much spill-over into the Tehuacán area.

During the rainy season, local rain storms amass in the mountainous areas in central Mexico to the west of the Tehuacán Valley. These storms may find their way over the Sierra de Zapotitlán to

the valley, but they are almost entirely restricted to small areas of precipitation whose distribution does not add up to much total effective rainfall for the valley. Were the rain from these local showers really effective, the summits of the Sierra de Zapotitlán would support a much different flora.

Mountain farms

Most farms of the oak-pine forest area are located on sloping ground. Under the most extreme conditions, fields are plowed on slopes greater than 45° from the horizontal. In all cases, the contour lines of the slope are rigidly followed and the field is broken by earthen dikes along the contour to arrest any water flow which might break through the furrow lines. The distance between these dikes is regulated by the angle of the slope.

Since the rainfall on the upper slopes of the Sierra de Zongolica is greater and more regular than that in the valley, all crops are grown with moisture available from precipitation. I saw only corn and beans planted in these fields, but squash or gourds are probably grown at other seasons. As peppers, tomatoes and many other vegetables require moisture during critical periods of their growth or moderate moisture throughout the growth period, they are not grown in the majority of the mountain fields. Seeds are planted in deep hollows in the bottom of the furrow, several seeds to a hole, so that all moisture is channeled to and accumulated around the plants. In spite of moist soil conditions during the summer rainy season, competition from weeds did not seem to be a major problem. The several weedings required in temperate zone fields do not appear to be needed here.

Except on the steepest slopes, the mountain fields are apparently cultivated for a number of years. In and around the village of Apala, where the slopes are gentler than on the adjacent mountainside, fields belonging to the families of the villagers were fully cultivated to the very walls of the farm buildings. These fields have probably been in almost constant use for many years. On the steep slopes, apparently wash and rapid drainage of the ground water lead to an earlier impoverishment of the soil with resultant abandonment. The fields grass over and are then pastured. Older abandoned fields gradually become covered with shrubs, but the re-entry of the original species of the oak-pine forest seems to be retarded. No apparent reason for this could be seen in the condition of the soil, nor do the areas currently pastured appear to be regularly burned. The answer

may lie in the fact that an adjacent patch of the mountainside is usually cleared for the new field and successive abandonments and clearings finally remove the seed source to too great a distance before the abandoned fields are in condition to receive and hold tree seedlings. Inroads by grazing animals may play an important part in the retardation.

FIG. 12. At Apala the fields have apparently been in constant use for many years, yet the slopes show no appreciable sign of erosion. Far below near Coxcatlán, the regular rectangles of irrigated fields devoted to growing sugar cane may be seen.

Valley farming

The agriculture in the Tehuacán valley proper is more complex than is cultivation of the mountain fields. This is true because of two major factors: the rainfall in the valley area is sparse to the point of inadequacy and unpredictable and the crops grown are far more varied. While the natural vegetation of the area would indicate a general dryness hardly suited to much crop cultivation, the level areas of the Tehuacán valley are among the most intensively culti-

vated localities in Mexico. The intensity of cultivation and the time over which it has been maintained approach those of the Valley of Mexico.

Within the valley area three major types of agriculture are practiced; two are closely related, the third is the normal outgrowth of the first two. First, and probably basic to the agriculture of the valley, is the cultivation of the alluvial soils in the barrancas which cut deeply into the flanks of the Sierra de Zongolica. Second, is the cultivation of marginal land with dry-farming techniques wherever an area seems adaptable to this (probably dependent to a large extent on the ownership of property since this kind of agriculture is practiced by families who often appear to have little material wealth and are perhaps "squatting" on the areas which they use). Third is the very highly developed and intensive cultivation of large irrigated areas of the level valley floor land and the less steep hillsides.

Barranca farms

Like many of the drier areas of the tropical and temperate portions of the world, the Tehuacán valley area has a scant vegetational cover. The amount of rainfall in the rainy season is not sufficient to enable a continuous turf of herbaceous vegetation to cover the ground closely. The almost total lack of rainfall during some months of the year means a severe competition for available moisture among the shrub and tree species. Where this competition is particularly heavy, the cover on the land is more scattered; even in the most densely "forested" places, the land is not closely covered with vegetation. Through the centuries, erosion has cut deeply into the mountains, forming barrancas which have gradually widened and allowed alluvial deposits to accumulate next to the base of the slopes and in the inside of the curves of the watercourses. This soil is both fertile and friable so that it furnishes an easily worked expanse. Because these watercourses are the principal drainage collectors for the mountains behind them, moisture can be depended upon for the development of crops planted in the proper season.

The fertile alluvial soils of this part of Mexico are utilized to their fullest capacity for the cultivation of a wide variety of crops. Since the larger part of the populations of the several towns and cities of the valley does not have the means to buy the packaged and canned foods used in the large cities, every settlement of moderate size in the valley has a market where the inhabitants purchase their daily food needs. The diet of the people is based on corn, beans, peppers

FIG. 13. Plowing the carefully contoured sloping fields with a yoke of oxen.

FIG. 14. Along the Barranca de San Antonio near the town of Necostla, extensive areas of the alluvial fields are covered with lattice frames. In the foreground are the tops of several platano plants.

and a minimum of fresh vegetables and fruit. With the available market in mind, the farmers of the barrancas plant most of the area available to them to corn, beans, peppers and squash or gourds. Some areas are devoted to smaller crops of "tomaté" (*Physalis* sp.), "jitomate" (*Lycopersicon esculentum*, the tomato commonly used in the United States) and a few other vegetables. In the yards, fruit trees are planted to furnish both shade and marketable fruit. "Aguacate" (*Persea americana* Mill., both the large mild-flavored avocado and the small, purple, anis-flavored avocado), mango (*Mangifera indica L.*), "chico zapote" (*Achras zapota* L.), mamey (*Calocarpum-mammosum* (L.) Pierre), "anona" (*Anona* sp.), "guajava" (*Psidium guajava* L.), "zapote negro" (*Diospyros ebenaster* Retz.), "zapote amarillo" (*Pouteria campechiana* (HBK.) Baehni, var. *salicifolia* (HBK.) Baehni), "zapote de niño" (*Couepia polyandra* (HBK.) Poir.), "tempesquistle" (*Bumelia laetivirens* Hemsl.), "plantano" (*Musa pardisiaca* L.), and banana (*Muas sapientum* L.), may all be found around the homes of the people. Occasionally, onions, garlic and some of the herbs for flavoring are grown but these are never planted very extensively. Small patches here and there near the dwellings are crowded with flowers to be sold in the markets.

Animal husbandry does not play a very large part in the type of farming carried on here. Oxen are kept to pull the plows; one seldom sees finer animals than the matched yokes of oxen owned by some of the farmers. Almost every household keeps chickens of a nondescript breed, half-wild turkeys and sometimes one or two ducks. Some pigs are raised, but seldom more than two or three animals per farm. Burros supply the chief trucking power and a wealthy farmer may keep a riding horse, but dairy cattle are few. A few range cattle and numerous sheep and goats graze on the pastures across the hills but these animals are kept well away from the cultivated fields.

Barranca fields are frequently bounded by the hills on one side and the watercourse on the other. Property lines are not at all regular. The soil is prepared by plowing with a wooden plow with a single steel share (wooden shares are used by the poorer farmers) drawn by a single yoke of oxen. The plow is guided by a single upright handle and the oxen are managed with a line or long goad. Furrows are plowed deeply on the contour of any slope with small dikes placed near the margins of the fields if water erosion is expected. Planting of corn and beans is accomplished by dropping several seeds into a hole dug in the furrow at intervals of 10 inches to 1 foot. Since these fields are generally moist, they must be weeded.

In the Barranca de San Antonio, extensive plantings are devoted to long, cylindrical gourds (*Luffa* sp.). Large lattice structures resembling the lath houses of the nurseries in the United States are erected over the fields. The vines clamber over the top and the developing fruits hang below in the shade of the lattice but up away from the ground. Since the structures erected for the support of the vines are substantial, it is evident that this specialized development is permanent on the fields where it is practiced.

Wherever rather broad valleys come to a head against the mountain side, the alluvial deposits are cultivated across the entire breadth of the valley. Since the surface run-off from the surrounding hills is not carried in a watercourse, elaborate precautions are taken to channel the water to the crops in a series of small flows that spread over the entire area. The center of the valley, dependent upon the slope of the valley floor, is crossed at intervals by stone check dams against which the upper field is graded in terrace fashion.

The level area toward the center of the valley is plowed from side to side. As the margin of the valley is approached, furrows are plowed in at diagonals, which may intersect each other, to reduce the cutting of erosive streams of water. Whenever major flow is expected, a dike two or three times the height and width of the normal deep furrow is placed to intercept or direct the water flow. If the area of cultivation is carried up into the base of the hillside, this area is carefully contour-plowed. The end result is the ultimate use of every drop of water which falls or flows onto the cultivated field without the loss of crop or topsoil due to gully or sheet erosion.

The major portion of the furrowing is accomplished by the plow drawn by a yoke of oxen. A heavy hoe is the principal hand tool used; shovels are used for terrace-building and well-digging. As in the areas previously discussed, corn and beans are the principal crops grown.

Dry farming

The second farming technique which is used over wide areas of the Tehuacán valley is dry farming. The northern end of the area around the village of Azumbilla and areas to the west toward Zapotitlán, near Teloxtoc, the villages of Calipan and Acatepec and near San Juan Atzingo in the hills beyond San Gabriel Chilac are all devoted to the growing of crops with the scant available rainfall. In

FIG. 15. The town of Acatepec is surrounded by fields being cultivated with dry farming techniques since little surface water is available for irrigation in the western portion of the Tehuacán area.

many of these areas, the basal geological formations are limestone which further reduces available moisture by excessive subsurface drainage. The increased fertility of the basic soils weathered from the lime rock may supply the ingredient which results in successful cultivation of these fields.

Around all the population centers, cultivation of the land is very intensive. Scarcely a square inch is allowed to remain uncleared of the shrubs and cacti, the normal vegetation cover for these hills. The long rows of "maguey" which serve as property divisions attest to the fact that the fields are permanently cultivated. Few plots of ground are obviously abandoned to fallow once they have been cleared for use.

Since much of the cultivated area used for dry farming is on hill slopes, all the fields are carefully contoured to prevent erosion and capture the moisture. Many of the fields are rocky and the larger rocks are used to build barriers on the downhill side of the field to retain the soil and raise its level so that fields long under cultivation become a series of low step terraces. As in the barranca areas, all devices for controlling and directing the flow of water are employed for providing as much moisture as possible for the growth of crops.

The principal crop grown in the dry farming area is corn. Furrows are plowed very deeply, and the seeds are planted in holes in

the furrows so deeply that seedlings 8 to 10 inches tall can scarcely be seen across the tops of the furrows.

Some fields around Azumbilla are devoted exclusively to the cultivation of selected strains of "tuna" (*Opuntia* sp.) which are grown for the fleshy, juicy fruit. The "tuna" varieties are propagated from cuttings placed in the field in rows at the beginning of the rainy season. Although it takes several years for the plants to reach fruiting size, an established plant seems to bear successfully for many years. The plants soon become large and branched so that shrubby weeds are eliminated by both shading and root competition. Gathering the harvest must present its problems in the form of numerous spine wounds.

The many maguey plants which occur both as boundary lines between the fields and naturally in the wild areas of the valley, are an important source of income for many farmers. The cultivated forms serve mainly as a source of pulque and fiber, but little of the plant is wasted since sections of split, dried leaves serving as short boards are used to cover walls shingle fashion and are bent to furnish a ridge capping for thatched roofs. The stalk of the inflorescence is used as a long smooth pole in an area where trees grow neither fast nor tall enough to become poles. The flower buds of one of the wild species are gathered, chopped and prepared as a vegetable commonly served with eggs.

The dry hills around the dry farming sites literally jump with herds of sheep and goats. The only vegetation not grazed is that which is poisonous or too spiny. The latter category is difficult to achieve, though, for even the formidably armed barrel cactus of the Tehuacán valley is nibbled by the goats. It is reported that many of these flocks never have a permanent source of drinking water but depend on the moisture from the succulent vegetation and the few puddles available immediately after a rain. The flocks apparently remain out continuously except when animals are being selected for sale or slaughter; at that time the flocks are confined in thornbrush corrals.

A few cattle are grazed near the villages, and the other animals usually kept by these farmers are oxen for plowing and burros for carrying. The lack of proper pasturage requires that valued draft animals must be fed with forage cut and brought to them. The few cattle that are grazed on the dry hillsides are thin and obviously in poor condition.

Farming with irrigation

The third kind of agriculture practiced in the Tehuacán valley is that carried on by means of irrigation. This is a highly developed technique. In recent years the Mexican government has installed concreted sloughs with mechanical gates in the extreme northwestern part of the area. The area served by these modern distribution canals is eclipsed by the multiplicity of integrated irrigation networks covering the major part of the valley. Most of the irrigation waters follow old canals and land-holding patterns.

Tehuacán valley is fortunately situated in an area with much lime rock formation which acts as an aquifer to accumulate the waters of the Sierra Madre Oriental to the east and the mountain masses of central Mexico to the west. In the higher northern end of the valley, numerous large springs with heavy flows furnish the mineral waters for which Tehuacán is famous throughout Mexico. Tehuacán, San Lorenzo, El Riego, Peñafiel, and Garci Crespo are household words signifying bottled waters and fruit-flavored soft drinks prepared by the several bottling companies owning rights to water from the springs. Many of these springs have a surface flow far in excess of the needs of the bottling plants and they serve as supply for irrigation systems based on old water rights ownerships. Several, like El Riego springs, no longer have sufficient flow to carry to the surface, but the galleries in the lime rock formation have been carved through the years to accumulate a maximum amount of water which is carried through tunnels down the valley until the level of the surface intersects the plane of the tunnel.

Spring water is not the only source of irrigation supply for the Tehuacán valley. Surface drainage has been gathered and concentrated by a number of means to fill the irrigation channels. Far up the barrancas into the mountains, the stream beds are dry, not from a lack of water from the mountains, but because an efficient system of wing dams and channels has gathered the flow into a system wholly owned by landholders through family rights. The water is jealously guarded and carefully used. The Rio Salado, with a bed a quarter mile wide, has a flow about 0.5 m. deep and 3 m. wide as it passes Pueblo Nuevo 40 km. down the valley from Tehuacán. This is in the middle of the rainy season when scattered showers and some widespread rainstorms have thoroughly wet the surrounding hills. Irrigation works and the water distribution facilities in the towns and cities of the valley have captured the major portion of the flow of the river.

Many times mounds of earth appear in regular procession across the valley near the margins or lie in a line up the barrancas into the mountains. These are the vent holes, with circumferential dump piles, for tunnels which are part of the irrigation system. These vents are opened to the surface at intervals of 100 to 200 yards because the tunnels are maintained and have been dug by hand labor. They serve both as air supply for the laborers and as a means of disposing of buckets of spoils cleaned from the tunnels 35 to 40 feet beneath the surface of the ground. When a hill is in the line in which a tunnel is dug, the laborers bore through to the other side without vents.

Water rights and property ownership in the valley obviously have developed over a long period of time with additional parcels of property and additional irrigation facilities being added as the need arose. Today the irrigation channels cross the valley in many directions

FIG. 16. The spring at San Lorenzo furnishes water for bottled drinks and irrigation water for large areas of the valley around Tehuacán.

and on many different levels. Frequently, the fields to be watered from one system are divided by fields watered from another system so that the separate irrigation facilities cross one another. Ditches carrying water from the hills must stay as nearly on a level as possible; intervening quebradas are bridged by aqueducts of masonry or wood and corrugated metal. Since the railroad through the valley is maintained on a grade which sometimes cuts through the hills, irrigation channels on the hill are carried under the track by an inverted siphon arrangement.

A major irrigation channel approaches the edge of the escarpment which forms one of the steps crossing the valley at San Andrés. The main stream is carried along the edge and is tapped by smaller channels carrying the water down the steep slope to service the fields below. Each of these major drops in elevation in the area has apparently been used over a very long period of time as a means of spreading the distribution of irrigation water for a considerable distance across the valley.

The fields under cultivation from the irrigation systems are carefully engineered to maintain a level expanse. If the level area is sufficiently large, a single field may cover a number of acres. Where the slopes are more precipitous, the fields are reduced in size until fields on the hillsides are a series of terraces. The terraces are sometimes held by stone retaining walls but more frequently by earthen dikes. Terraces may be as much as 10 to 15 feet high at their outer edge, but the usual rainfall in the area is seldom sufficient to cause troublesome erosion on the terrace bank.

Within the fields, the furrows are carefully contoured to distribute water evenly from the sides. The water is often brought to the field by a header channel so that irrigation can be effected from both sides of the field at once. The earthen dike on the field side of the channel is breached near the top of the field first and then at intervals down the side of the field. Water is allowed to run about a third of the distance across the field in the furrows from either side before it is shut off. This apparently is sufficient to provide moisture completely across the field. Fields appear to be completely soaked only before the crop is planted.

Because these fields are permanent, several means are used for restoring soil fertility after a period of use. The fields are sometimes fallowed; the vegetation growing on the fallowing fields when I was in the area would indicate that the fields were out of use for one to three years. The brush is then cut and bundled for transport to the

potteries where it is used for firing the furnaces used to bake roof tiles. The ground is plowed and prepared in the normal manner for use.

Some of the fields in the vicinity of Tehuacán are fertilized with manure. Truckloads of manure are spread over the fields before they are plowed. Little evidence of chemical fertilization was seen. Chem-

FIG. 17. Terraces south of Tehuacán which were soaked before planting. Note the dense strand of cane (*Arundo donax* L.) along an irrigation ditch just beyond the terraces.

ical fertilizers are available in the cities and a trunk from the larger farms is sometimes seen loading sacks of fertilizer, but the farmers as a whole are unable to afford such material since the local market for produce and crops does not provide a very high income.

The crops grown on the irrigated fields are varied. The usual food crops—corn, beans, and peppers—are grown. Many fields are devoted to alfalfa which is cut and transported to one of the two or three driers devoted to drying forage material. Sugar cane is grown to supply the mill at Calipan.

Even the banks of the irrigation channels are used to good advantage. Frequently cane (*Arundo donax* L.) grown here is cut both for the tops, which provide forage material, and for the canes, which are put to a number of uses. In Chilac, the enclosures around prop-

erty are frequently made of cane. Large loads of cane are frequently seen on the backs of burros along the highway which runs through the valley. In an area where cane is scarce in the natural vegetation, cultivated cane is utilized to its fullest extent.

Modern animal husbandry has become established in the city of Tehuacán. Surprisingly, there are several dairies in the city and a large chicken farm at the edge of town. Since there is inadequate pasturage for dairy cattle in the surrounding countryside and the animals are maintained on forage provided for them, the dairies are maintained as close to the customers as possible. The cows are fed and kept in restricted areas from which the milk is distributed in bulk in cans carried on the backs of burros. Milk is sold by the measure from the bulk container. The poultry farm is quartered in modern brick buildings, apparently with all the recent techniques of the United States poultry farmer used as they are applicable to this business in a Mexican city.

Development of agricultural techniques

The specialized techniques used in the Tehuacán Valley are not a recent innovation. No program of education has induced the farmers to adopt recently developed patterns of plowing to aid in the control of water flow over the surface of hillside fields. Governmental aid has stepped into the development of concrete-lined channels with permanent water control devices in the northwestern part of the valley. Introduction of different crop plants has been largely restricted to the addition of alfalfa for forage to the crops normally grown in the area. With the alfalfa has come the dryer for quick-drying the crop for easy storage. The intimate knowledge of the land and its potential and limitations has been handed down from past generations who learned long ago to select varieties suited to the climate and work the land to best advantage.

The careful contour, deep-furrow plowing practiced by the upland farmer on the Sierra de Zongolica undoubtedly is the result of many bitter experiences of some distant ancestor. Today the farmer still works with the most primitive mechanical aids. The Spanish Conquest of Mexico brought oxen to the New World and, with them, the plow to cut a deep furrow. The heavy hoe used for hand work in diking the margins and field areas liable to erosion is probably little different from the tool used in the distant past.

The area occupied today by the mountain farmers is an area new to the people. The amount of forest still remaining uncut on the

mountain mass indicates this; it is also indicated by the condition of the abandoned fields. The grazing animals, the sheep and the goats, brought to Mexico by the Spanish, can be held largely accountable for the lack of effective regeneration of forest tree species in the brush-grown clearings. The lack of truly serious gullying and soil slippage on most of these abandoned fields indicates that they have not been subjected to repeated clearings, plowings and abandonments. These would have left their traces in much more severe erosion, particularly since the mountain fields in the belt above 1800 m. elevation are subjected to more rainfall than the land in the valley. Such misuse will eventually occur as the mountain areas immediately above the valley will be completely cleared of forest within the foreseeable future. Over-grazing, which will add to the problem by removing the protective vegetational cover, is imminent.

The network of irrigation systems and the many techniques used for the control of water in the fields under irrigation are not recent developments either. The physical labor alone, which has been expended in terracing the fields and digging and diking the irrigation channels, is staggering. Add to this the labor represented by the tunnels which run for miles beneath the surface of the valley; the time required to do all this hand work is beyond the imagination. A mechanical digging device has never touched a major part of the irrigation networks currently in use nor have they received a sealing liner of concrete. Over the years the channels have acquired an impervious lining from the precipitation of minerals in the water.

The mineral lining of the irrigation channels identifies numerous raised dikes cutting across abandoned areas of the valley as the remains of older irrigation works. In some places, current usage has obviously been superimposed on much older use of the land. Where land has had to be abandoned, probably because of eventual salting of the ground through continued use of spring water with a very high mineral content, the outlines of terraces and the lines of the channels remain to mark the sites of old fields. Today the erosion of the fields has progressed to a point where the bottom of the old mineralized channel is 2 to 3 feet above the surface of the ground. If the loss of a quarter-inch of soil a year is assumed, estimated time since first use of the fields would be about 100 to 150 years. As no extensive gullying is found in these areas and there is no indication of sorting of material in size classes, such as is usually found in water erosion of any type, the possibility of water erosion is strongly re-

FIG. 18. The courses of ancient irrigation channels stand boldly above fields in which the soil is apparently so heavily impregnated with salts that even the native vegetation does not grow well here.

duced. Wind erosion would, thus, seem to be indicated. Early in the year, near the end of the long winter dry period, the wind blows consistently and strongly for days at a time. This could be the erosive agent which has excavated the fields and left the irrigation channels standing stark and abrupt where they were formerly dug into the surface of the ground. The rate of removal of the soil is reduced, however, by the shrub vegetation which covers abandoned areas. No loess piles remain in the protected angles where the base of the channel meets the surface of the field, as would occur with a strong wind blowing primarily from a single direction. With continuously shifting winds, erosion would be markedly reduced as the loose soil blown in one direction one day would blow in another direction another day and the net effect of random stripping and replacement would be considerably less. It is hardly conceivable that the valley area has suffered from a quarter-inch of top soil blown into the air in any one year as this should show as marked wind erosion on the trunks of trees, on painted surfaces, on stuccoed buildings and on the rocks of the hillsides themselves. The rough surface of the limestone

of the hill outcrops has much more of the appearance of solution weathering than the smooth polishing of wind-blown soil particles.

The evidence is, then, that the erosive process which has removed as much as three feet of soil from comparatively level fields in the vicinity of Tehuacán has been a very gradual one. Better established evidence than the circumstantial evidence provided by an unmeasured rate of erosion supports this. The remains of terraced fields and irrigation systems to provide water for them have been found in the Tehuacán Valley in association with abandoned villages and cities. Some of the latter were extensive urban developments judging from the size of the remains of the public buildings and the extensive area over which the dwelling remains are to be seen. Associated with the fields and irrigation works as well as the remains of the buildings are artifacts and sherds which correlate with the Classic Palo Blanco period in the area dated at about 200 B.C. to 800 A.D. (MacNeish, 1961). Thus, the involved techniques for the control of water in irrigation systems and terraced fields can be assigned an age of at least 1000 years in the area and they probably date from the beginning of the Classic period; the use of these techniques can be placed at 2000 years in the past.

Prehistoric developments

In spite of the age of the irrigation works associated with datable remains in Tehuacán valley, the story of agriculture must go far beyond this. Such refined methods of farming could have developed only over a long time span. The development of agriculture in the valley can be reconstructed from the current practices employed on the dry farms and the farms of the barrancas. The necessary facts needed to cultivate the dry slopes of the hills of the valley successfully and to harvest sufficient crop from the fields to feed the population of the immediate neighborhood, include (1) a knowledge of annual cycles of weather and (2) the proper methods of working the soil. The first comes from long residence in the valley and the knowledge that the moisture available for crops will be scant but reasonably predictable through the months of the growing season. The second will come only from generations of trial and error which gradually lead to an intimate knowledge of the laws of hydraulics and soil structure. This process of trial and error could not possibly have been carried out on the dry farm sites or the total population would have starved while searching for the proper means of growing a crop. A gathering economy based on the sparse native vegetation would

have taken every available minute of time to support a very large group of people. Much time could not have been wasted on the trial and error method. The methods employed in this form of agriculture must have been adapted from techniques developed in some other place.

The barrancas cutting deep into the flanks of the mountains provide an ideal setting for research tracing the development of man's techniques for controlling water in motion. These valleys provide the collecting systems by which water is brought into the valley. The water flow has, in fact, created them through geological time. These sheltered areas could provide the moisture needed for the greater development of plants whose fruit, leaves, stems, roots, and insect parasites could be used for food by a gathering economy. Streams flowing during part of the year and providing soil moisture the rest of the year would have maintained a more steady food supply. One must assume, then, that the settlers of the valley came to the barrancas for protection and for food. The open Tehuacán valley was too inhospitable; the mountain slopes above were too heavily forested to provide a setting for the beginnings of agriculture.

The moist alluvial fans and the deposits along the water-course down the barranca provided the conditions of moisture and the fertility needed for successful farming with little knowledge of the means of accomplishing it. Morever, the semiarid climate provided another asset; the natural vegetation was light and the incipient farmers could plant without clearing the land. The people who may have been the direct ancestors of the Indians who own and farm parts of the Tehuacán valley today, must be assumed to have been pioneers not only in developing a form of plant husbandry adapted to the climate of the area, but they may well have the distinction of having originated the idea of cultivating food plants to ensure an easier harvest. The earliest date at which the people may have practiced some form of agriculture has not been established. That they were cultivating corn about 5040 B.C. is certain since corn remains have been conclusively dated by C^{14} tests (Peterson, F. A., in litt.).

The dating of cultivation of other plants has not been established finally, but a number of other plants such as squash, gourds, pumpkins, beans and amaranth have been recognized among the vegetal remains excavated from archeological sites at Coxcatlan and El Riego caves. No means of proving the cultivation of such plants as maguey and tuna is available as these have not become highly modified

through selection under cultivation due to their propagation by vegetative parts.

The last point is one which can cause considerable argument. Both "maguey," in many forms (since there are at least eight species native to the Tehuacán area) and "tuna" (with many more species native to the area) have been among the most prevalent plant species recognized among the plant remains discovered in the excavations. Seed of *Opuntia* spp., "tuna," are in the soil and debris from all the levels for which preservation was adequate to preserve any plant parts. Fibrous quids, parts of leaves and strips of fiber of maguey are found in the earliest levels in which softer plant parts are found. All the remains could have come from wild plants in the area.

I firmly believe, though, that the ease of propagation of these plants and their preferred status as food plants for the people of the area early led to attempts to concentrate plants of a desired species in one spot near the dwelling site. The advantages of such a practice are obvious. Instead of long trips to collect tuna fruit or maguey leaves which may have taken the people far across the Tehuacán valley into open areas, plantings could be successfully made on the alluvial soils in the protected barrancas. To this can be added the ease of collection of the desired amount of the plant within a short period and the protection which the planter could give his crop to prevent its being harvested by other persons. Also, the neophyte farmer soon learned that food in excess of his own needs could be bartered for something which he wanted from someone else.

The beginnings of agriculture must have had the very simplest tasks reduced to a minimum. For a person struggling for an existence by gathering and hunting, there would be no leisure. Even if food were abundant during parts of the year, the territory considered to be property of a person or a group of people would have to be defended from encroachment. Earliest agriculture might have been a move toward reducing the area which would have to be guarded against encroachment. Whatever the reason, someone saw fit to bring together several plants of a kind which he considered of value.

The easiest possible site for planting crops must have been the more open stretches of alluvial soil. Happily, these had not only been kept partially clear by flooding, but the fertility of the soil had been concentrated and was frequently refreshed by the same water action. Moreover, the drainage pattern was such that, even in the absence of a surface stream, the soil was frequently moistened by subsurface drainage. Hardy succulent plants like maguey and

tuna would do well here where the work of planting would be minimal and the work of caring for them could be reduced to preventing their removal by others.

Once the initial success of such a planting had been established, the subsequent development of other plantings could not be prevented. No one truly knows what may have come next. The idea of concentrating important food plants like "tuna" and "maguey" may have spread widely before anyone thought of adding a herbaceous plant to the garden. Perhaps the development of gardens of a variety of plants proceeded rapidly to the ultimate result, the selection of better seed for the next season's crop. It may well be that the idea of planting spread outward first, and someone in another area decided to add other plants to the garden and their use spread back into the first territory.

Whatever the sequence of events, it is now known that species of plants commonly cultivated throughout most of Mexico were brought into cultivation in different areas and at different times. The species of Cucurbita show this in some detail since cucurbit remains have been recovered in most of the archeological excavations where plant remains have been preserved. The evidence indicates that *Cucurbita pepo* perhaps came into cultivation first in northern

FIG. 19. Dry farm near Acatepec. "Tuna" and "maguey" are growing adjacent to the house. Hanging under the eaves are two bundles of palm leaves (*Brahea dulcis*) which will be woven into hats. Beyond the house is a stack of maguey "boards" against which maguey poles are leaning.

FIG. 20. The remains of an ancient check dam near Teloxtoc in use during the Classic (Palo Blanco) period. Erosion has since deeply gullied the foreground and dug an arroyo 12 feet deep along the main watercourse.

Mexico, where it can be dated as early as 7000 B.C., probably occurring as a wild, weedy plant in the environs of campsites (Cutler and Whitaker, 1961.) At the time of the Cutler and Whitaker summary the earliest finds of *Cucurbita moschata* had been made in the Huaca Prieta excavations at Chicama, Peru, in South America. These finds can be dated as early as 3000 B.C. *C. moschata* is in the Ocampo Cave excavation in Tamaulipas, Mexico, where it is dated 1850 B.C. *Cucurbita* mixta can be dated A.D. 150 in Tamaulipas, Mexico, whereas *C. mixima* had been found only in Peruvian deposits dated A.D. 600 at the earliest. As additional records become available from more sites in Mexico, the pinpointing of the centers of origin of cultivation of these plants will become more exact and the dates at which they were brought into cultivation in the various areas will be modified. The Tehuacán project has added dates of 300 B.C. for *C. pepo* and 4,400 B.C. for *C. mixta* and C. moschata (Cutler, H., in litt.)

The Tehuacán valley people probably cultivated the fertile soil of the barrancas long before they overpopulated them and had to move down into the broad open areas of the valley. During this period of development, the occurrence of rainy season floods and the failure of plantings in drought years brought about a gradual change in cultural methods to prevent water damage from floods and to better use the available moisture in the soil of elevated fields. The first was accomplished by a series of check dams and dikes and the last by careful contouring and channelling of water during the times when it is available, all of which was described in detail. Since this refinement in the methods of farming the alluvial soils of the barranca has left no artifacts by which the process may be dated, one can only infer that the development of methods of diking and contouring took many hundreds of years.

Significance of the Tehuacán valley in relation to other American archeological sites

The Tehuacán valley has been selected as the critical area in the unraveling story of the establishment and diversification of *Zea mays* in cultivation in aboriginal America. The first maize from excavations made in 1960 has been reported by P. C. Mangelsdorf and W. C. Galinat to be "wild corn and/or wild corn in the first stage of domestication." The maize material from excavations in 1961 and 1962 still has to be analyzed in detail to determine the progress of selection and modification of corn in the Tehuacán area, but it is already evident that this cereal was among the most important annual crops introduced into the agriculture of this dry region. One of the species of *Cucurbita* may have been cultivated as early as corn. It is still too soon to determine whether *Phaseolus* or *Capsicum* was present very early in the development of agriculture here.

One fact is apparent from the currently available information: the first cultivation of the annual food crops must have been undertaken in fields or areas nearby under the same semiarid climatic regimen as exists today without artificial means of providing additional moisture for the developing crop. The apparent stability of climate in the Tehuacán area will be discussed in a later paper. Little likelihood exists that the flow from the valley springs would have been utilized at first because control of flowing water is a highly complex technique. Plants native to an area of high rainfall would be very unlikely to survive on the restricted amount of moisture available and the attendant lack of knowledge of highly specialized techniques among the farmers. The annual crop plants must origi-

nally have been native to the same or similar areas with a semiarid climate. Could wild maize have been a native grass of the barrancas of semiarid areas of Mexico and have been largely eliminated by a 400 year history of grazing by the sheep and goats introduced by Spaniards from the Old World?

Evidence from other archeological sites in Mexico, however, indicates the need for caution in dogmatically determining the center of origin of any cultivated plant on the basis of present knowledge. It is imprudent to state categorically that maize was first brought into cultivation in the Tehuacán area although all the available evidence strongly supports this idea. Similarly, all evidence currently available indicates that *Cucurbita pepo* was first brought into cultivation in northern Mexico, but it is too early to assume that this finding is final. Evidence from many more archeological excavations throughout tropical America from Mexico to Chile is needed to settle finally the time sequence involved in the movements of crop plants from one area to another and to permit naming the actual centers of origin of all plants brought into cultivation in the Americas.

Once again, the care used in preserving all the vegetal material recoverable from an archeological excavation is proving its value. At the time of my first experience with this sort of material, while participating in the excavation of the deposits in Bat Cave, New Mexico, in 1948, a veteran archeologist visiting the site remarked that such "trash" from his excavations in the southwestern United States had hindered the recovery of artifacts and had sometimes been burned. Botanists have long been aware of the hazards involved in theorizing about the origin and distribution of plant species on the basis of contemporary collections and it is comforting to know that incontrovertible evidence in the form of paleo-botanical records sometimes can be found to support hypotheses. Since modifications induced in plants through man's efforts, subsequent to cultivation of a species, always introduce changes in the timetable for such modifications far different from those which can be expected in wild plants, it is increasingly important that the extent of these modifications, the rapidity with which the modifications arise, and the dissemination of the modified forms from their center of origin be as carefully recorded as possible on the basis of plant material recoverable from archeological excavations.

Equally important is the recovery of wild plant material from the same excavations so the composition of the flora in times past can be

accurately reconstructed. With sufficient evidence from the wild plant remains, an ecological study will provide a key to climatic changes even though the changes have been minor fluctuations. Often the pattern of weather changes in the past can supply valuable information for the botanist trying to interpret changes in food habits of a people and it may explain changes in the crop plants themselves.

One especially significant interpretation from the Proyecto Tehuacán is the indication that the present culture of the Tehuacán valley does not differ materially from the culture of the area at the time the Conquistadores first entered the valley and divided the land into haciendas. Probably the Spanish rulers were wise enough to permit the people to continue their farming in the ancient methods which are so effective here. Overlordship apparently merely changed from Indian to Spaniard the person who collected the profits. A detailed study of the present society should establish the extent of the changes within historical times so that they may be used as yardsticks against which to measure other areas in Mexico. One interesting facet of this would be the status of the group of Indian women who supply most of the tortillas for the Tehuacán market and daily trot from their village to the city with baskets of their products on their backs. Such customs certainly go far toward substantiating the theory that little change has taken place. It would be more economical for these people to prepare and cook their wares in Tehuacán because modern transportation would make the transporting of supplies a minor matter.

The bulk of the plant remains from the Coxcatlán Cave deposit has not been analyzed. Thus, the fluctuations in food preferences and the changes in wild plant material being brought into the cave cannot be detailed. All the material from the first season's excavations was examined in 1961 while it was being sorted into related age lots according to the stratigraphy in the excavation. In the process, cultivated plant materials were separated for attention by the several experts who will analyze these remains. Any fragment that appeared to be markedly different from the bulk of the plant material was closely examined with a lens and compared with other material from the same level. None of the apparently foreign fragments were worthy of special attention. Most of these could be correlated with larger pieces or different parts of the same species of plant; on close examination, a few proved to be wisps of animal fur mistaken for pochote fiber or fragments of animal skin put among the plants as bark or leaf pieces. Often seeds from fruits had been

cracked or broken in an unusual plane, but none of them turned out to be entirely different or unexpected.

Evidence from the several excavations throughout Mexico which have yielded plant remains leads to two conclusions. In the first place, wild plants were always actively gathered during the entire period of occupation at all the sites. While the cultivation of crop plants may have relieved the people from gathering food, no distinct break occurred in the gathering of plant materials. Today, we have no knowledge of the reasons for bringing in certain plants; certainly many of the grasses and other small herbaceous plants had very few uses other than as bedding for people without domesticated ruminant animals. Many of the plants were probably gathered for medicinal purposes or they may have had some meaning for the people based on local superstitions. Still other fragments were undoubtedly gathered in play by children. The bulk of plant materials recovered in all the Mexican excavations dry enough to have plant preservation were gathered for food, fiber, oil or other useful products.

The second conclusion from the plant remains recovered in Mexican sites is that the overwhelming majority of the plant species represented are Mexican in origin. It is to be expected, of course, that wild plant fragments would be locally gathered. So far, very little evidence for the trading of wild plant material from a distant area has been found. Far more surprising, in the light of the many theories of cultural diffusion conceived by anthropologists, is the predominance of Mexican plant species among the very useful and widely cultivated food crops. Prime among these is maize whose Mexican origin was long speculative; the material discovered in the Tehuacán valley removes any doubts about the area of origin of this cereal. Maize, the primary starch source for the peoples of the New World, was widely cultivated by the Mexican Indians. Several kinds of beans were used by the early Mexicans. The common bean (*Phaseolus vulgaris* L.), the sieva bean (*Phaseolus lunatus* L.) and the tepary bean (*P. acutifolius* var. *latifolius* Freem.) have all been in cultivation in Mexico since early in the history of domestication of plants. The common beans are known to have been in cultivation as long as maize, or longer. Pumpkins and squashes (*Cucurbita pepo* L., *C. mixta* Pang.) are also early cultivars in Mexico, as are gourds (*Lagenaria siceraria* (Mol.) Standl.). Of these, only gourds may have come into cultivation outside Mexico. A number of other cultivated plants of less importance, such as amaranth and sunflower,

have been found in excavations in Mexico where they were brought into cultivation. Among the non-food plants, cotton (*Gossypium hirsutum* L.) and tobacco (*Nicotiana rustica* L.) were widely cultivated native Mexican plants.

The evidence now available indicates that the only major food plant originating in South America which may have been introduced into Mexico is yuca (*Manihot dulcis* (J. F. Gmel.) Pax). Fragments of this were found associated with the artifacts of the Palmillas culture in the Ocampo Caves in Tamaulipas (MacNeish, 1958b; Kaplan and MacNeish, 1960) which are dated by C^{14} determinations at about A.D. 200. The South American tobacco (*Nicotiana tabaccum* L.) may also have come into Mexico before the time of the Spaniards. However, all the major food plants (except *Cucurbita pepo*) of the Mexican area (maize, beans, chilies) had found their way into South America at an early time. In South America, the Indians brought into cultivation a number of native plants, including the tomato,[1] potato, "aracacha," "oca," and "quinoa," many of which were of sufficient use to attract the attention of the Europeans, who lost no time in introducing them into the Old World. Had there been much regular communication between the Mexicans and the South Americans, these plant species would have been introduced into Mexico.

Tentatively, then, it can be concluded that communication between Mexico and western South America was uncertain and that cultivated plants were gradually disseminated between the two areas. This was undoubtedly from hand to hand through neighboring people since the less important crop plants from both directions were filtered out in passage. Only crops of sufficient worth to require repeated effort to maintain them and of sufficient inherent variability to allow their adaptation to a variety of cultural conditions, actually made the slow journey from one area to the other. The plants involved were those originating in a semi-arid habitat which presupposes a genetic complex enabling the wild progenitors of the crop plants to persist under very adverse conditions.

Significance of the Tehuacán area in relation to Old World findings.

During recent years, archeologists interested in the development of cultures in the Old World have begun to investigate the remains

[1] There seems to be some confusion concerning the place of the tomato in Mexican agriculture. The Indian people of the Tehuacán area apply the name to *Physalis* sp. and recognize the *Lycopersicon* plant as an introduced plant known as jitomate. The latter plant probably was a very late introduction from the south.

FIG. 21. Seedling corn and bean plants nearly eight inches tall barely seen across the deep furrows.

of villages which predate the major and classical civilizations but which antedate the Paleolithic cave occupations. As in the New World, every attempt is being made to reconstruct the sequence of climatological events as well as the related vegetation so that an accurate picture may be drawn of the beginnings and development of agriculture. Here the beginnings of agriculture apparently are connected with the initiation of village groups, as they are in the Americas.

Far more is known about the Paleolithic developments in the Old World than is known about a similar period of development in this hemisphere. Workers can draw these developments into a climatological picture (Solecki and Leroi-Gorhan, 1961) related to the Pleistocene geological events. Many of the climatic changes have obviously had a marked effect on the vegetation of an area which is duly recorded in the amounts and kinds of pollen deposited in a site. The time intervals of most interest to the present discussion are the Proto-Neolithic and Neolithic during which the climate was entering a dry phase. The climate has changed remarkably little up to the present (Braidwood and Howe, 1960).

Of more direct bearing on the problem of the beginnings of agriculture and village life are the reports of the recovery of evidence for the initiation of villages in several places in the Near East. Kenyon (1956, 1959) has traced the village of Jericho to its beginnings at about 8000 B.C. Here the local people formed a village in the area of natural springs with artifacts indicating Mesolithic cultural development. Obviously the initiation of agriculture must have been a concommitant accomplishment to support a stable population. The people of this period lacked knowledge of pottery-making which is often believed to be a companion development of agriculture and the rise of settled communities. The growth of the Jericho culture continued into the Neolithic period without pottery. Interestingly enough, Kenyon found a statigraphic break and cultural changes indicating the influx of another people (her Pre-Pottery Neolithic B) with a developed architecture and, obviously, with agriculture, who also lacked pottery, indicating the parallel development of cultivation and settled communities in several areas at about the same time. While the dating of the site has been queried, I have no basis from which I can dispute it.

Braidwood and his associates (Braidwood, and Howe, 1960; Braidwood, Howe and Reed, 1961) have been following the development of villages and agriculture in Iran. Currently available evidence points to the rise of agriculture in the Iranian hills during roughly the same period as that covered by the settlement at Jericho. The initial developments in tilling and cropping the native food plants apparently took place about 7000 B.C. Furthermore, the climate of these areas has probably undergone little change since then. The floral and faunal remains from which the paleoecology has been reconstructed indicate that available precipitation was at about the same level as today.

Other analyses of plant remains recovered from archeological sites have added much to the knowledge of the development of agriculture in the Old World. Among the more enlightening, is the analysis of material discovered in Egypt in a tomb complex of the third dynasty dating about 2900 B.C. This, of course, has little to do with the development of agriculture since practice of the art of tillage had long since become widely established and knowledge of many of the important food crops was widespread. An interesting commentary from the report by Lauer, Tackholm and Aberg, 1950, is the summary statement, "Neither the [native] vegetation nor the [native] species themselves differ in the slightest from the vegetation

and species existing nowadays [in Egypt], in spite of the intervening 5000 years." The cultivated crops included barley (*Hordeum vulgare* L. var. *pallidum* Ser.) and wheat of two forms (*Triticum dicoccum* Schubl. and *T. monococcum* L.).

Of particular interest to the story of agriculture in Tehuacán is the report on an intensive development of irrigation farming in the Negev of the Near East at a comparable period (Evenari, Shanan, Tadmor and Aharoni, 1961). While the remains of irrigation projects are not precisely dated by the report, the statement is made that the area was relatively densely populated as early as 2000 B.C. implying that there must have developed an intensive agriculture dependent upon irrigation. Terracing and channeling to lead the the water to areas of cultivation were standard practices. Tunnel systems with vent holes (here called "'chain well" systems) were employed for collecting water. One major difference from the situa-

FIG. 22. Irrigation water cascading down the slope of the scarp at San Andrés. Water from the springs in the valley above is led along the edge of the scarp so that spaced lateral channels like this one can provide water for fields across the width of the valley below.

tion in the Tehuacán valley is the extreme drouth of the Negev area which led agriculturists to develope large watershed areas for the collection of run-off to supply water for the fields.

In addition to the development of the cultivation of the cereal grasses wheat and barley, a number of other crops were developed in the Old World. Field pea, lentil and blue vetchling are associated with the remains recovered at Jarmo, Iraq. Later, flax for oil and grapes for wine were added to the roster of crop plants. At about this time, both olives and dates were apparently becoming widely distributed in cultivation. As the art of cultivation spread, only highly adaptable crops such as the cereals became modified to survive in differing climatic regimens and local plants of value in the food economy were added.

This brief survey of the development of agriculture in the Old World repeats several facts of utmost importance to the understanding of the initial development of agriculture. Paramount among these is the fact that the plant selected for cultivation must be native to the area and adapted by long survival under the prevalent climatic conditions. Needless to say, ease of cultivation must be associated with the easy gathering of a crop from a concentrated assemblage of the plant. As in the New World, it cannot be expected that the earliest agriculturists would have thought to a logical conclusion from the facts gleaned under a gathering economy. While the initial impulse to concentrate food plants so that they might be more easily gathered was undoubtedly the force behind the establishment of techniques of cultivation, the processes of tilling and selecting seed for subsequent seasons must have evolved only over a long period with many more failures than successes. Only by using plants already adapted to a local situation was it possible for the early farmers to achieve any measure of success.

Over the 7000 to 9000 years covered by the recent finds relating to the beginning of agriculture, climate has been remarkably uniform. In all instances now known, cultivation began in an area of restricted rainfall. Compared to the "norm" for areas where the largest amount of the world's food crops are now grown, the areas where agriculture began are marginal at most. For economic reasons, people inhabiting these places still continue food production, at least for subsistence, and they often still employ the techniques developed very early in the history of cultivation of plants. In some instances, the population of an area has declined and been replaced. Where the knowledge of the old farming techniques has been completely lost, recent mi-

grants into the area must begin the experimentation anew or reconstruct ancient techniques from archeological evidence, as in the Negev of Israel.

Obviously, the development of agriculture has followed similar patterns in the Old and New Worlds, but the crops have differed. Evidence leads to the supposition that the New World pioneers of the Tehuacán valley area may have first concentrated plantings of succulent perennials such as "tuna" and "maguey," whereas the neophyte farmers of the Old World probably started with the cultivation of annual crops. The local situation in which the hunters and gatherers first started to concentrate food plants was probably the same. In both the Tehuacán valley and on the hill slopes of Iraq and Palestine, the native vegetation of dry hillsides could most easily be planted on alluvial soils where periodic washing had kept the ground free of woody vegetation. Here also the concentration of moisture would more surely presage success in a small number of attempts at planting. This would have had to be successful with little initial effort, for these people could spare little time from their demanding routine of gathering and hunting.

Diffusion of cultures and dissemination of crop plants

Much verbiage has been devoted to the diffusion of cultures from one area to another and from one hemisphere to another. Germaine to this discussion is the multitude of reports of Vavilov and his associates on the centers of selection of varieties of cultivated plants. Botanists with a broad knowledge of phytogeography and a detailed knowledge of many diverse species have contributed. Other botanists with an intimate knowledge of only a single group of cultigens have entered their arguments. Geographers with little knowledge of facts, but much influence, have had their say. Anthropologists, ethnologists and archeologists have all entered their arguments into the discussion.

The prime fact that has emerged at present is that the soundest of the opinions have generally been based on an intimate knowledge of the plant world. There can be little interpretation of the evidence when based on the correct identification of a species since the morphological traits of an individual plant are the expression of part of its genetic composition. These same controls cover the physiological reactions of the plant to its habitat. If the limits of these are known, and they are known in detail for the more important crop plants, it is obvious that the plant can be induced to persist

only within its limits of tolerance. By his techniques, man can broaden the limits only moderately.

By and large, no evidence whatsoever is available that any repeated or prolonged contact was made between the Old and New World before the time of Columbus. It is not necessary to discuss the many arguments in detail since current evidence from sound archeological work and recovered plant remains points to only one conclusion. A few cases will have to be mentioned in detail only because of the nature of the botanical evidence upon which the opinions are founded.

First, let us consider the current evidence for the diffusion of plants from one local area to the next. Helbaek (1959) has provided a tentative timetable for the distribution of wheat. On the basis of his intimate knowledge of the archeological remains of plants found in Old World sites, he can place the origin of cultivation of wheat in Iraq roughly about 7000 B.C. Within the next 2000 years, wheat had been adapted to the fields of the lowland drainage basins in the Near East and Egypt. By about 4000 B.C. the cultivation of wheat had spread into the Danube basin and around 3000 B.C. it had spread well through Europe. Here an interval of 4000 years was consumed in moving a major crop plant from its point of initial introduction into cultivation to the furthermost western point it could reach. No doubt can be had that this must have been a most valuable cultigen to the early peoples of the Old World. It had the inherent variability which allowed its adaptation to various climatic situations. Yet it took a considerable time for the cultivation of of the wheat plant to cross the continent of Europe. This timetable is still approximate since further archeological finds will undoubtedly change some of the dates. The initial date, particularly, may change as much archeological work must still be done in the Near East. By and large, though, the overall picture of the diffusion of a crop plant has emerged with startling clarity.

A similar picture can be constructed for maize in the New World, but with much less confidence that intermediate dates will not be changed. The date for the beginning of the cultivation of maize may be nearly terminal. By the process of elimination through the analysis of maize material from archeological sites to north and south of Tehuacán, this was localized as the probable region of the origin of cultivation of maize. The Coxcatlán cave deposits, which have a maize sequence far earlier than any other now known, show the appearance of maize as early as 5000 B.C. Maize spread northward

through Mexico and reached New Mexico by 2500 B.C. In the archeological deposits of coastal Peru, maize did not appear until about 750 B.C. Here it entered an area where agriculture was already well developed and, had maize been available earlier, it would almost certainly have appeared in the deposit due to its great importance to people who had no major starch source because the potato is principally a highland crop. Here again, the spread of a major cultigen was slow in spite of its obvious value to the people of the Americas. This must be due to the rate of diffusion of knowledge of the plant since it is highly variable and readily adapted to many different climatic situations.

Other crop plants follow a similar pattern of spread and similar time scale. The picture emerging for squash in America has been discussed previously, but it is of sufficient importance to review briefly here. *Cucurbita moschata* was in cultivation in coastal Peru at about 3000 B.C. It appears in the deposit in Tehuacán, Mexico at about 5000 B.C. *Cucurbita pepo* appears first in the Tamaulipas deposits at about 7000 B.C. There is no evidence that this species reached South America before the time of the Spanish. *C. pepo* did not diffuse far southward, but became an important crop plant in the area which is now the southwestern United States. Obviously, crop plants have come into use initially in diverse areas; in spite of their potential as food sources they have not spread in the same directions or at the same rate.

The lists of plant species recovered in archeological excavations also point up another very pertinent fact. Local food preferences always persist in the local area, but the food is not palatable enough to cause wide demand from neighboring people or, probably more important, the species does not have sufficient inherent variability to allow its adaptation to a variety of soil and climatic conditions. If a wild plant is valuable enough to a group of people, it is usually moved into cultivation in the local area. This does not necessarily mean that it will become an important crop plant for another group.

Diffusion of crop plants between the hemispheres

Because the areas are similar, the important crop plants from one hemisphere should be successful crop plants in the other. This is now taken to be a commonplace fact as wheat and maize are widely cultivated in areas far from their places of origin. One can, of course, name crop after crop for which this statement holds true.

In all the archeological excavations from which plant materials have been recovered, there is no indication that any plant native to the Old World was carried to the New World or vice-versa in pre-Columbian time. The plants which would have been most favored for importation into a new area by a group of colonizers or explorers would be plants which were the staple food of their diet. Wheat or maize would certainly be the two most favored grains to be taken as supplies for a trip and as seed to plant a new crop. Neither has been recovered outside of its native hemisphere in a context placing it with remains datable before A.D. 1492. The expectation that a more local crop might have made such a journey and become successfully established is even more remote. There is no evidence that any minor crop plant was transferred from one hemisphere to the other in pre-Columbian times.

The evidence of dissemination of the sweet potato

One plant undoubtedly became widely distributed in the Old World cultural complex in the Pacific islands from its original home in the Americas but there is no archeological evidence for this distribution. The sweet potato (*Ipomoea batatas* Poir.) was probably picked up from people inhabiting the west coast of South America and carried by Polynesian explorers to the islands of the Pacific. This transfer apparently occurred about A.D. 1200—the approximate date for the arrival of the sweet potato in Hawaii. Sweet potato was found in the Pacific by botanists on the Cook expedition. It is the only plant of American origin known to the Polynesians; all the rest were brought by them from the west.

No other cases are known in which evidence for pre-Columbian diffusion between hemispheres is sufficiently valid to warrant discussion. Most of the plants discussed in anthropological literature are minor crops of the people who have used them. One or two plants have acquired some religious or magic significance. None of them have been of sufficient importance that a special effort might have been made to carry them across an ocean. Furthermore, no archeological evidence has ever been found that any plant has been transported between the hemispheres. The case of the gourd (*Lagenaria siceraria* (Mol.) Standl.) has been amply discussed (Cutler, and Whitaker, 1961) and there is no reason to doubt that this plant was naturally distributed in the New World long before it became a cultivated plant.

FIG. 23. Crude windlasses mark the vents of an irrigation tunnel which empties into the ditch in the background.

SUMMARY

The agriculture of the Tehuacán valley is a series of highly refined techniques for utilizing the low available precipitation to grow maize, beans, peppers, alfalfa, sugar cane and other crops necessary to feed the people of the area and their stock. Clearing of the higher mountain sides in the zone of the oak-pine forest above the 1800 m. level appears to be a relatively recent development. These fields are very carefully contoured for water control and there has been relatively little erosion to this time. Fields are being abandoned to become grassy pasture and then brush areas in which the tree species do not appear to become re-established.

Three types of techniques adapted to the special problems in local areas are found in the valley proper. The first of these is the use of alluvial soils in the deep barrancas which cut into the flanks of the Sierra de Zongolica. Here contouring, diking, low-terracing and other means are used to retain as much water as possible for the developing crops. These areas are quite probably the original loci of the development of techniques used in the cultivation of the rest of the valley.

Dry farming is practiced in many parts of the area. Deep contour furrowing, terracing and deep seeding allow the development of crops of maize and beans with available moisture. "Maguey" and "tuna" are important crops; the former for fiber, pulque, boards and poles, the latter for fruit. This type of farming was derived from the barranca farm methods.

Irrigated fields are wide spread across the valley floor. Many different water systems, which cross each other in a complex pattern, are in use. Only in the northwestern portion of the valley have some of the channels been modernized with concrete bottoms and mechanical control gates. The largest portion of the irrigation works are based on very old developments and still employ the old channels.

Water comes from every available source. The large mineral water springs in the north end of the Tehuacán area furnish both the bottled waters and soft drinks famous throughout Mexico and, also, a large part of the water for irrigation. The flow in the Rio Salado and its tributaries is picked up and turned into the irrigation systems. Across the valley and into the mountains, tunnels, whose courses can be followed by the line of dump piles around the vent holes, have been dug. A wide variety of crops are grown year after year on the irrigated fields. Only rarely are valley fields allowed to fallow one to three years. Manure seems to be the fertilizer most used. Little evidence was seen of chemical fertilizer use although it is sold in the area and trucks from the larger farms have been seen with partial loads. By and large, the farmers of the valley cannot afford chemical fertilizers since their income is from the limited local market.

The irrigation systems and the highly refined method of farming have an ancient past. Old remains of irrigation channels and terraced fields have been associated with the urban ruins and artifacts of the Classic Palo Blanco period which can be dated about 200 B.C. to A.D. 800. Some of the old irrigation channels, now abandoned, bordering fields near Tehuacán, are at least three feet above the present level of the field; since they are normally at field level, they must be very old to have weathered three feet out of the ground. They have persisted because of the impervious mineral lining which is deposited in the irrigation channels by the mineral waters of the springs.

Since the methods of dry farming and the use of the alluvial soils of the barrancas must be considerably older than the use of irrigation, the story of farming in the Tehuacán area is very old indeed. Culti-

vated plants recovered from the excavation of Coxcatlán Cave indicate that agriculture was developing in the area around 6000 B.C. Because the remains of "maguey" and "tuna" are found in consistently large quantities in the archeological material and the climatic regimen has apparently been stable throughout the entire time period represented by the deposits, probably the cultivation of these plants originated in the barrancas of the Tehuacán valley. With concentration of maguey and tuna plants on the alluvial soils of the barrancas, the crop could be protected and more readily gathered while the favorable soil and moisture would insure successful plantings. Once the success of the initial plantings was assured, it was only a minor step to the planting of other desirable plant species.

Maize was brought into cultivation in this area; remains recovered in the early levels appear to be wild maize or maize in the first stages of cultivation. Maize was probably a grass of the semidesert area on the lower slopes of the Sierra in the protected barrancas. While it may yet be found as a wild plant, the possibility is rather remote because of four centuries of grazing by sheep and goats which were introduced by the Spaniards.

From the evidence now available, it is believed that different crop plants in the Americas came into cultivation at different times and in different areas. This is particularly well illustrated by cultivated *Cucurbita; C. pepo* was apparently introduced into cultivation in northern Mexico, whereas *C. moschata* originated in Central America.

We can now see that the dissemination of cultivated plants from one area to another is relatively slow unless the plant is very basic to a food economy and is highly variable so that adaptations may be selected for successful cultivation in various soils and climatic conditions. Maize moved from Mexico to Peru over about 4000 years. To date, only the most important crop plants have been found to have moved from one area to another; minor crop plants are restricted to local areas. Yuca (*Manihot* sp.) is the only plant known through archeological evidence to have made the journey from South America to Mexico. Many plants, on the other hand, have found their way from north to south.

The development of agriculture in the Old World took place only slightly earlier than it did in the New World. In the Old World, techniques of farming revolved around the cultivation of the annual grains—wheat and barley. The area in which the rise of agriculture in the Old World took place is remarkably similar to that in Mexico; it is a semiarid region of upland where initial attempts at cultivation

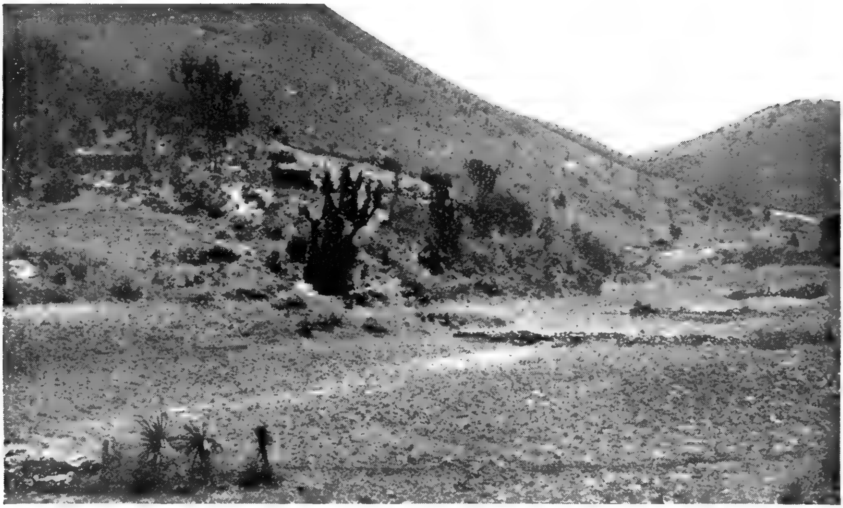

FIG. 24. The head of the valley above Azumbilla is intensively cultivated. Stone check dams prevent gullying down the center of the valley and raise the lower edge of the fields. The furrows run from side to side across the center of the valley, but the slopes are carefully plowed on the contour.

FIG. 25. A field of corn and beans growing right up to the wall of a building in Apala. Slopes still partially covered with oak-pine forest are in the background.

undoubtedly occurred on alluvial soils. Moisture was more readily available, periodic flooding had renewed the fertility of the soil and, more important, had kept the area free from large woody growth. The ancient neophyte farmer had to know nothing about the techniques of farming and he did not have to work to prepare an area for planting. The gatherers and hunters of both hemispheres made the happy discovery that the partially clear alluvial soils of the upland water courses could be used as areas in which to concentrate the food plants they found desirable. Here the crop could be protected and much more easily gathered.

Distribution of the techniques of cultivation of wheat spread westward from the place of origin (perhaps in Iraq) at about the same rate as maize moved southward from Mexico. In the Old World it took about 4000 years for wheat to reach the shores of the Atlantic on the western edge of Europe. It is a highly variable crop plant from which forms could be adapted to the soils and climatic conditions encountered from the semiarid Kurdish hills to the damp western coast of Europe.

No archeological evidence exists that a plant had been carried from the Old World to the New World or vice versa. Botanical evidence indicates that the sweet potato had been carried into the Pacific area, apparently by Polynesian explorers who visited the western coast of South America. All other supposed introductions from one area to the other can be shown to be erroneous conclusions due to misunderstanding of some of the broad biological implications of the facts, for example, cotton, or the obvious early natural distribution of a plant, as in the case of the gourd.

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